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POWDERY MILDEW, PODOSPHAERA LEUCOTRICHA (E. AND E.) SALM.*

ITS APPEARANCE, CAUSE, AND CONTROL.

By G. H. CUNNINGHAM, Biological Laboratory, Wellington.

POWDERY mildew although very frequently neglected by the orchardist is one of the most serious diseases with which he has to contend. It is prevalent throughout the fruitgrowing areas of New Zealand, and becomes especially troublesome during the late summer and the early autumn. It would appear that this disease originated in western North America, and from there it has spread to almost every country where apples are grown, for it has been recorded from Europe, Asia, and Australasia.

In New Zealand powdery mildew is confined to the apple, but in Japan it occurs on an additional host, *Pirus toringo*, and in North America has been recorded (though seldom) on the pear. So far as the writer is aware no apple varieties are immune, but certain varieties are more susceptible to attack than are others, Cox's Orange, Jonathan, Sturmer, Cleopatra, London Pippin, Gravenstein, and Northern Spy being usually severely infected.

ECONOMIC IMPORTANCE.

This disease causes the leaves to become much smaller in size, crinkled, brittle, and darker in colour. Infected leaves fall prematurely, so that about midsummer severely infected trees appear partially defoliated. Shoots, if infected early in the season, become stunted and often so weakened as to die at their tips, often losing their foliage, when they appear quite bare. Fruit-buds are damaged to such an extent that the resultant blossoms seldom set fruit. Fruits may be attacked while immature, with the result that at maturity they appear russeted and smaller than the normal. At the stem end they frequently become scabbed and cracked. In short, the effects of mildew infection are (1) the reduction of leafage and damage to the remaining foliage, (2) destruction of fruit-buds, (3) weakening and frequent killing of laterals, and (4) reduction of the marketable value of the fruit by russeting, cracking, and frequent deformation. Further, young nursery stock may be damaged to such an extent that wood-growth is entirely prevented; consequently such stock becomes unsaleable.

* Synonyms: *Sphaerotheca leucotricha* Ell. and Ev.; *S. mali* Burr.; apple-mildew; mildew.

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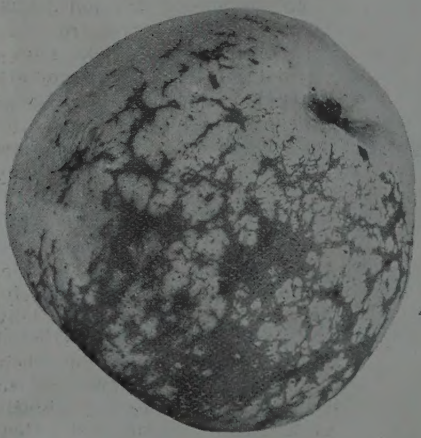

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FIG. 1. TIP OF A STURMER APPLE LATERAL ATTACKED BY THE POWDERY MILDEW FUNGUS. HALF NATURAL SIZE.

Further growth is prevented, and the subsequently formed leaves remain small and strongly curled.

FIG. 2. INFECTED APPLE LATERAL FROM WHICH THE MATURE LEAVES HAVE FALLEN. SLIGHTLY REDUCED.

Note the stunted leaves, and especially the white mycelial mass covering the upper portion.

FIG. 4. DUNN'S FAVOURITE APPLE RUSSETED AS THE RESULT OF EARLY INFECTION. NATURAL SIZE.

Although not noticeable, the near side is much deformed.

[Photos by G. H. Cunningham.

APPEARANCE AND EFFECT ON THE HOST.

Trees infected with powdery mildew present a very sickly appearance; they become partially defoliated, and carry about one-fourth of the leafage of a normal tree. The shoots are often bare at their tips (Fig. 2), and are partly covered with the glistening white masses of the fungus. The fruit is smaller than the normal, and usually disfigured.

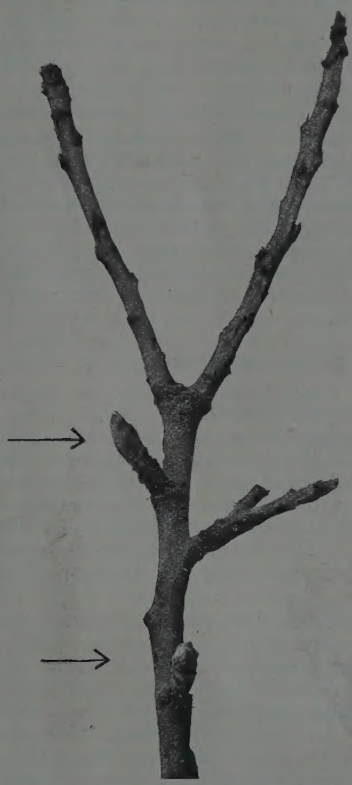

FIG. 3. APPLE-SHOOT INFECTED THE PREVIOUS SEASON. SLIGHTLY REDUCED.

Note the bunchiness of the laterals, their small size, and the closeness and small size of the buds. Normal buds indicated by arrows.

[Photo by G. H. Cunningham.

Powdery mildew attacks leaves, shoots, blossom-buds, and fruits. On the leaves it first becomes noticeable in the form of small, irregular, white or greyish cobwebby patches. These make their appearance first on the under-surface of the leaf, and gradually spread until both surfaces may become entirely covered, when the leaf appears as if covered with flour. Leaf-infection first occurs as soon as the leaves emerge from the bud, and the fungus spreads progressively from these to subsequently formed leaves. Infected leaves become narrower and rather longer than the normal. At first they appear somewhat blistered, then the edges gradually curl inwards until they appear markedly distorted (Fig. 1). Later they become brittle and have a scorched appearance. Finally they change to a bronze colour and ultimately fall away.

Laterals are infected shortly after the leaves have emerged from the buds and immediately after they have begun to increase in length. Infection occurs from the leaves, the hyphæ growing down the leaf-stalk (petioles) to the young shoots. As a result of infection growth is somewhat checked, consequently the buds are more closely set together (Fig. 3). When infection is severe the tips of the shoots are killed, and the following season several small shoots spring from below the killed area, the resultant shoots presenting a "bushy" appearance (Fig. 3). The fungus continues to develop on the shoots until they become covered with a white felt-like mass, more abundant near the tip, which consists of the mycelium or vegetative portion of the fungus (Fig. 2).

Infected blossom-buds are somewhat smaller than the normal, and are conspicuous by reason of their covering of white mycelium. When the buds expand and the blossoms appear, the calices and stalks are seen to be somewhat deformed and altered in colour. Infected blossoms rarely set fruit, and are invariably later in appearing than the normal blossoms.

The fruits are infected shortly after blossoming, and at this stage may be seen to be partially covered by the fungus. At this stage the delicate epidermis becomes damaged, so that later, when the fruits approach maturity, the epidermis is seen to be decidedly russeted, the markings appearing either as a delicate brown or yellowish tracery over the surface (Fig. 4), or as scabbed and deformed areas on one side, but more frequently on the stalk end of the fruit. This may be followed later by the appearance of concentric cracks which usually extend some distance into the flesh and afford opportunity for the entry of spores of soft-rot fungi; consequently fruit from trees infected with mildew rarely keeps well for any time. The writer has not observed the hyphæ of the fungus on other than very small fruits. The fruits of all varieties do not appear to be attacked, as russeting has not been observed on fruits of Cleopatra, although the leaves and shoots of this variety suffer severely.

LIFE-HISTORY OF THE CAUSATIVE ORGANISM.

Powdery mildew is caused by *Podosphaera leucotricha*, a fungus having two spore stages in its life-cycle. The first or conidial stage is produced throughout the growing season on the felt-like masses of mycelium which cover the surfaces of infected leaves and shoots; the second or perithecial stage in New Zealand appears about the middle of March (although it would appear to be common in midsummer in North America) in the form of small black bodies (perithecia) partially embedded in the mycelial masses. The conidial stage is the more important one, as apparently the perithecia play little if any part in the perpetuation of the organism.

If a small portion of the felt-like mass of mycelium is examined under a microscope it is seen to consist of very numerous, colourless, closely woven threads (hyphæ) closely applied to the surface of the host (Fig. 5, *m*). From these at intervals arise upright stalks (conidiophores) (Fig. 5, *con*) bearing on their free ends chains of colourless oblong conidia (Fig. 5, *c*). These are produced in such enormous numbers as to give the leaves and shoots upon which they may happen to be growing the appearance of being covered with flour. Should one of these conidia be carried by wind or other agency to the surface of a growing leaf or shoot, and conditions prove favourable, it germinates and produces a slender germ-tube (hypha), which grows over the surface of the substratum, branching repeatedly to form a mycelium. This consists of very numerous interwoven hyphæ, and derives its nourishment from the epidermal cells, into which small branches (haustoria) penetrate (Fig. 5, *h*) to absorb therefrom the necessary food substances. It is thus seen that with the exception of these small haustoria all the fungus is superficial. The hyphæ continue to spread over leaves and shoots during the whole of the growing season.

About the middle of March the perithecia make their appearance on the shoots, leaves, and petioles, appearing as small, globose, black objects densely crowded together, and partially embedded in the mycelium (Fig. 7). Each perithecium has on its free surface several bristle-like structures, which serve to characterize the species* (Fig. 7). Within the perithecium is a single large ascus containing eight one-celled, colourless ascospores (Fig. 7, III). Under humid conditions the perithecia absorb moisture and swell, and their walls become ruptured, allowing the ascospores to escape. Experiments carried out in North America (1914-18) would tend to show that the perithecia play little or no part in the perpetuation of the disease, as attempts made to infect young developing leaves with ascospores invariably failed.

The fungus is carried over from year to year by the felt-like masses of mycelium, which cover the buds, spurs, and tips of laterals, and by hyphæ which are enclosed within the scales of infected buds. This mycelium remains more or less dormant until the spring, when conidia are produced from the hyphæ, and these infect the leaves as they emerge from the buds, thus starting the disease afresh. Doubtless in many instances infection occurs from the hyphæ within the bud-scales, before the leaves emerge. It thus becomes apparent that the persistent mycelium is the source from which the fungus is spread in the spring; therefore in combating the disease the elimination of this mycelium should be attempted before any spray is applied.

CONSIDERATIONS REGARDING CONTROL.

As has just been shown, powdery mildew is perpetuated by the persistent mycelium (Fig. 2); therefore where systematic attempts are being made at control attention should be given to the removal of this source of infection. If all infected shoots and buds were removed, then the disease would be entirely eliminated and spraying unnecessary. Unfortunately, this cannot be accomplished in a commercial orchard, partly because the time required would be too great and the labour involved too costly, but principally because the disease is in part carried over in infected buds, which in many instances are not apparent from a casual inspection. Furthermore, infection would still be liable to occur from wind-borne spores from neglected orchards in the vicinity. Nevertheless, cutting out would minimize infection, especially spring infection, to such an extent that control by spraying would be rendered comparatively simple.

The crop would not be in any way lessened by the removal of infected shoots and fruit-buds, for, as has been shown earlier, infected buds are incapable of setting fruit. Therefore systematic control of powdery mildew must commence with the cutting-out of visibly infected material. This may be readily accomplished during the winter pruning, especially in New Zealand, where the system of pruning is such that practically every shoot is dealt with. If the disease were much in evidence during the late summer a further cutting-out could be undertaken.

* Recently the writer has obtained abundant perithecia from shoots of Sturmer collected at Ettrick, Otago. From the accompanying drawings it will be seen that the species in question is *Podosphaera leucotricha* (E. and E.) Salm. It is believed that the perithecia have not previously been recorded for Australasia.

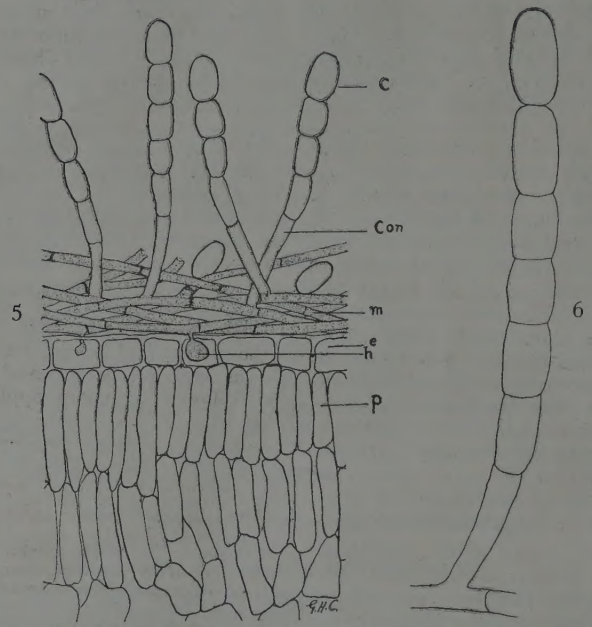

FIG. 5. SECTION THROUGH LEAF INFECTED WITH POWDERY MILDEW.

(*c*) Conidia; (*con*) conidiophores; (*e*) epidermis of the leaf; (*h*) haustorium; (*m*) hyphæ (collectively forming the mycelium); (*p*) palisade cells of the leaf, × 325.

FIG. 6. CONIDIOPHORE AND CHAIN OF CONIDIA, SHOWING METHOD OF SPORE PRODUCTION, × 600.

[*Original.*

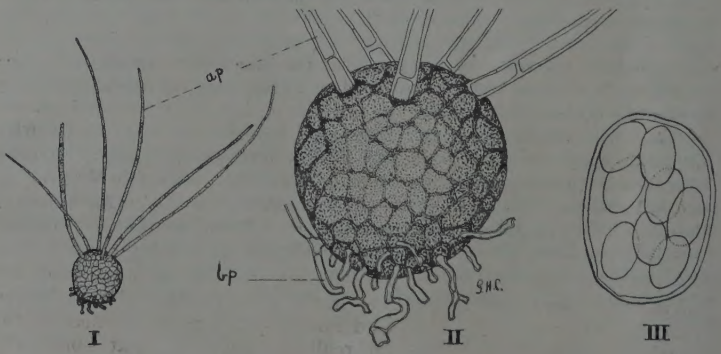

FIG. 7.

I. Perithecium of the fungus, × 85. II. Perithecium, × 330. Note the apical (*ap*) and basal (*bp*) appendages. III. Ascus and ascospores, × 330.

[*Original.*

From time to time numerous sprays have been recommended for mildew-control. Bordeaux, lime-sulphur, "iron-sulphide solution," atomic sulphur, and several variants of these have all been tried. Undoubtedly atomic sulphur has given the most satisfactory results. The iron sulphide solution has been favoured by numerous growers (this is a solution of lime-sulphur to which iron sulphate ($FeSO_4$) has been added), but consideration will show that this is merely a solution of atomic sulphur and iron sulphide (FeS), the latter compound possessing little if any value as a fungicide.

CONTROL.

(J. A. Campbell, Director of the Horticulture Division, Wellington.)

As powdery mildew is carried over the winter months by the patches of fungus which remain on the shoots and in the bud-scales, it is necessary that as many of these as are seen be removed during the winter pruning. This should be followed by spray applications according to the following schedule :—

No.	Time of Application.	Spray.
1	Between open-cluster and pink stage	*3–4–50 bordeaux, or preferably 1–30 lime-sulphur.
2†	Calyx (petal-fall, or when the majority of the petals have fallen)	1–100 to 1–120 lime-sulphur, or preferably 10–100 atomic sulphur.
3	Beginning of January	10–100 atomic sulphur, or 1–120 lime-sulphur.
4	Middle of February	10–100 atomic sulphur, or 1–100 lime-sulphur.

* Bordeaux is not as efficient a spray for mildew as any of the sulphur preparations, so that where black-spot is absent (as in Central Otago) it is better to use lime-sulphur, 1–30, at this stage.

† With this and subsequent sprays arsenate of lead, 3 lb. paste or 1½ lb. powder to 100 gallons, may be added for the control of codlin-moth and leaf-roller caterpillar.

Where a regular spray formula for black-spot control is being followed it will be found that mildew is held in check somewhat, but not entirely, as lime-sulphur is not altogether satisfactory as a controllant of mildew owing to the very weak strength (1–120) at which it is applied. A dual spray—lime-sulphur 1–120 + atomic sulphur, 10–100—is therefore recommended in place of lime-sulphur alone. The second black-spot spray would be lime-sulphur, 1–30, in preference to bordeaux, 3–4–50, as the latter is not as efficient a mildew controllant as the former.

The first two sprays in the schedule prevent leaf-infection from mycelium overwintering in the buds, No. 2 especially preventing russeting of fruits. The third and fourth sprays prevent infection from outside sources. It should be realized, however, that spraying is effective only where cutting-out has been practised in the winter. No. 3 spray should be followed by cutting-out, especially where the disease is prevalent.

SUMMARY.

(1.) Powdery mildew is a fungous disease attacking leaves, shoots, buds, and fruits. It occurs on apple, pear, and (in Japan) *Pirus toringo*.

(2.) The name of the fungus is *Podosphaeria leucotricha*, as has been definitely established by the recent finding of abundant perithecia.

(3.) The disease overwinters by means of resting mycelium on the shoots and in the bud-scales. It is spread in summer by means of conidia produced from mycelium covering leaves and shoots.

(4.) It may be controlled by the systematic cutting-out of infected shoots and buds during the winter pruning, and by spraying according to the foregoing schedule.

(5.) Atomic sulphur, 10 lb. to 100 gallons of water, is the most efficient fungicide to use as a controllant.

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